

The sensitivity of the pigeon's keypeck to the differential reinforcement of long interresponse times

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Keypecking of pigeons was studied under differential-reinforcement-of-low-rate (DRL) and variable-interval (VI) schedules in which the interreinforcement times on the two schedules were equated by a yoking procedure. Each schedule was available for half of every session and a change of schedule was signaled by a change of key color. The value of the DRL schedule was varied from .5 to 300 sec. Response rates were always higher in the VI schedule, but within sessions there was a sharp change in response rate coincident with the change in schedule only under lower schedule values. A group without prior training was tested with a 180-sec schedule value, and it, too, developed a higher response rate during the VI schedule, showing that the effect was not dependent on prior experience under low schedule values. In all conditions except the .5- and 1-sec values of the schedule, the mean proportion of responses emitted during the VI schedule was approximately .85 of the responses emitted during both schedules. The conclusion was that the requirement of a minimum interresponse time for reinforcement may work its effect by determining which responses may occur just prior to the reinforced response and thus receive delayed reinforcement.

The requirement of a long interresponse time (IRT) as a necessary condition for the delivery of reinforcement may affect behavior (Anger, 1956; Ferster & Skinner, 1957). The direction of the effect is to lower response rate. Richardson (1973) showed that the differential reinforcement of long IRTs as programmed according to the differential-reinforcement-of-low-rate (DRL) schedule resulted in a lower response rate than a variable-interval (VI) schedule equated for density and distribution of reinforcement. In order for this suppression to have occurred, the subjects must have been affected by the differential consequences of responses with IRTs shorter than and longer than 15 sec, the DRL value used in the study. The range of IRT duration under which subjects are affected has not been established. Some limits might be expected for IRT duration. Indeed, in the case of pigeons, it has been assumed that the keypeck response is insensitive to reinforcement of IRTs above 20 to 30 sec under the DRL schedule (Kramer & Rilling, 1970). However, Richardson and Loughhead (1974b) found that

response probability increased as a function of time since the last response, under very large DRL values. These data imply that the pigeons were affected by differential reinforcement of long IRTs and that the response rate at these values would be suppressed if compared to a VI control condition.

The primary purpose of this experiment was to measure the effectiveness of the DRL schedule in suppressing keypecking over a large range of DRL values. The technique used in the Richardson (1973) study involved separation of the measures of behavior under the DRL and VI schedules. In one condition, different subjects were used in the DRL and VI schedules (between-subjects comparison). In a second condition, the same subjects were tested under the DRL schedule for several sessions and then were tested under the yoked VI schedule. The present study used a multiple (mult) DRL yoked VI schedule which permitted daily measurement of the DRL behavior and the VI behavior of each pigeon.

According to the present analysis, the degree of control of keypecking by the differential reinforcement of long IRTs programmed by the DRL schedule could be measured as the ratio of response rate during the VI component to the sum of the response rates during the DRL component plus the VI component (relative response rate) of the mult DRL yoked VI schedule. If the pigeon is not affected by the IRT contingency, the response rate during the DRL and the VI components should be controlled by the rate and distribution of reinforcement during each component. As, under the mult DRL yoked VI

The data of Experiment II were collected by Larry G. Holder and were submitted to the Psychology Department in partial fulfillment of the requirements for graduating with honors in psychology. Portions of these data were presented at the 16th Annual Meeting of the Psychonomic Society, Denver, Colorado 1975. I wish to thank the Computer Center of Georgia State University for providing the computer time and the computer programs necessary to obtain and analyze the data. Reprints may be obtained from W. Kirk Richardson, Department of Psychology, Georgia State University, University Plaza, Atlanta, Georgia 30303

schedule, the rate and distribution of reinforcement are the same for the DRL and VI components, the response rates should be the same in each component (in the absence of control by differential reinforcement of IRTs) and the relative rate would be .5. If the keypeck response of the pigeon is sensitive to the contingency of the DRL schedule, then the relative rate should exceed .5. In addition, if the keypeck is sensitive to the size of the IRT requirement, then relative rate should vary as a function of the value of the DRL schedule.

IRT reinforcement theory requires that subjects are sensitive to the consequences of different IRTs; however, Reynolds and McLeod (1970) have argued that there is no evidence which requires an IRT reinforcement theory for its interpretation. They argued that DRL, differential-reinforcement-of-high-rate, and other schedules can be explained in terms of the control of response topography or collateral behaviors by the reinforcement contingencies. The results of the present study support this position.

EXPERIMENT I

Method

Subjects. Eight adult racing homing pigeons were maintained at 70% of their free-feeding weights during preliminary training and at 75% of their free-feeding weights during the experiment proper. The eight pigeons were divided into Group 1 (P1, P2, P3, and P4) and Group 2 (P5, P6, P7, and P8). Birds P4, P7, and P8 had previously served in an experiment using a DRL 30-sec schedule of food reinforcement. The other pigeons were naive at the beginning of the experiment.

Apparatus. The pigeons were tested in four identical operant chambers with the following inside dimensions: 52 cm long, 36 cm wide, and 38 cm high. The response panel in each test chamber had a keyhole, 2.5 cm in diameter and centered 27 cm above the floor. The response key was a translucent Plexiglas paddle. The rear side of the paddle was painted flat black except for a circle, 1 cm in diameter, which was centered behind the keyhole. The paddle was transilluminated with red or green light according to experimental conditions. A force of 15 to 20 g (.15 to .20 N) with an excursion of .1 cm was required to operate the response key. The houselight consisted of two 28-V bulbs placed behind a translucent Plexiglas screen located across the top of the response panel. The reinforcer was one 45-mg Noyes pigeon pellet delivered to a Scientific Prototype food tray centered 7.7 cm below and 5 cm to the left of the response key. A 28-V shielded bulb located 5 cm above the food cup directed light into the food cup for 1 sec when a reinforcer was delivered. A 75-dB re $20\mu\text{N}/\text{m}^2$ white masking noise was continuously present in the test chamber.

An IBM 1800 Data Acquisition System located in a separate room controlled the experimental contingencies and recorded responses.

Procedure. Each pigeon was adapted to its test chamber, magazine trained, and pretrained for four sessions in which every response was reinforced (approximately 100 reinforcers per session). The naive pigeons were shaped by the method of successive approximations to peck the response key during the first session of regular reinforcement. Next, all the pigeons were trained under a DRL 10-sec schedule for 38 sessions (Condition 1). During adaptation and magazine training, the key light

was red. During regular reinforcement and DRL 10-sec training, the key light alternated between red and green on a daily basis.

A mult DRL yoked VI schedule was used in all the succeeding conditions. Under this schedule, each session was divided into two parts (components) of equal duration. During the first component, which was signaled by the transillumination of the response key with a colored light, reinforcement was programmed according to a DRL schedule. During the second component, which was signaled by the transillumination of the response key with a different colored light, reinforcement was programmed according to a VI schedule yoked to the DRL schedule. The interreinforcement intervals programmed by the VI schedule were the interreinforcement intervals generated during the preceding DRL component, i.e., the programmed interreinforcement intervals of the VI schedule component were yoked to the actual interreinforcement intervals of the preceding DRL schedule component. This procedure closely equates the density and distribution of reinforcement between the two schedules. For example, during Condition 2, a red key light was present during the first half (20 min) of the session and reinforcement was delivered according to a DRL 10-sec schedule. During the second half (20 min) of the session, a green key light was present and reinforcement was delivered according to a yoked VI schedule. If the first reinforcement during the DRL component occurred 50 sec after the beginning of the session and the second reinforcement occurred 93 sec later, then the first two programmed interreinforcement intervals of the yoked VI schedule would be 50 and 93 sec.

The major variable manipulated was the parameter of the DRL schedule component (and thus the parameter of the yoked VI schedule component). The major difference between Groups 1 and 2 was the schedule values. Groups 1 and 2 were treated differently starting with Condition 3. Group 1 was tested under six different schedule values, which decreased in stepwise fashion from 10 to .5 sec and then increased in stepwise fashion back to 10 sec. Group 2 was tested under eight different schedule values, which increased in stepwise fashion from 10 to 120 sec and then decreased in stepwise fashion back to 10 sec (Condition 12). Condition 13 for Group 2 was a schedule value of 300 sec.

The sequence of key-light colors was occasionally reversed as a part of the change in conditions. For example, in Condition 7 of both groups, the schedule value was not changed but the key-light color of the first (DRL) component was changed from red to green and the key-light color of the second (VI) component was changed from green to red. At other times, the key-light colors were reversed simultaneously with a change in schedule value. See Table 1 for the sequence and details of experimental conditions.

Before a session began, each pigeon was placed in a dark test chamber. At the start of the session, the houselight and key light were illuminated. At the end of the session, all lights were extinguished. The DRL schedule programmed reinforcement for every response with an IRT equal to or greater than the DRL value. The IRTs were measured as the time from the beginning of the session to the first response and thereafter as the time between two successive responses. The VI schedule programmed reinforcement for the first response that occurred after the elapse of each successive interreinforcement interval. The timing of interval $n + 1$ did not begin until the reinforcement for interval n was delivered. The pigeons were tested 5 days a week, Monday through Friday.

Conditions were changed when at least 10 sessions of testing had occurred and each pigeon had five successive sessions where the response rate during the DRL component showed no systematic change. As the procedure was new, a conservative approach was always used when judging the stability of the behavior, especially for the initial conditions. Under the low schedule values, the session duration used was as long as possible under the restriction that the weights of the pigeons remain stable. The session durations used for the larger DRL values were limited by the availability of the computer and test chambers, but were always set long

Table 1
Experimental Conditions and Reinforcement Rates

Condition-ordinal position	Stimulus order	DRL value (sec)	Session duration (min)	Number of sessions	Reinforcement ^a per hour	
					DRL	VI
Group 1 (P1, P2, P3, P4)						
1	Red or Green	10	40	38	91.3	(93.2)
2	Red-Green	10	40	46	83.0	82.0
3	Red-Green	7	30	17	183.5	155.5
4	Red-Green	5	24	34	298.7	288.8
5	Red-Green	3	14	25	637.0	612.4
6	Red-Green	1	4	10	2321.3	2071.9
7	Green-Red	1	4	10	2253.8	2017.5
8	Red-Green	0.5	4	10	2476.6	2158.1
9	Red-Green	3	14	15	661.6	641.9
10	Red-Green	5	24	15	351.6	345.0
11	Red-Green	7	24	20	169.4	168.1
12	Green-Red	10	40	29	102.7	101.3
Group 2 (P5, P6, P7, P8)						
1	Red or Green	10	40	38	100.7	(118.1)
2	Red-Green	10	40	36	132.3	131.1
3	Red-Green	15	60	27	41.3	41.1
4	Red-Green	20	60	32	29.5	29.4
5	Red-Green	30	80	16	13.5	13.5
6	Red-Green	45	120	15	8.5	8.5
7	Green-Red	45	120	15	5.5	5.5
8	Red-Green	60	180	15	6.7	6.7
9	Green-Red	120	180	24	6.5	6.5
10	Green-Red	45	120	19	5.6	5.6
11	Green-Red	20	60	14	20.3	20.3
12	Green-Red	10	40	15	85.5	85.5
13	Green-Red	300	180	24	2.2	2.1

^aThe reinforcement rates for Condition 1 are for the first (left column) and last (right column) half of the DRL 10-sec session.

enough to, in my judgment, give reliable response measures, i.e., the session-to-session variance was not greatly affected by session duration.

Results

The transition from DRL 10-sec to mult DRL 10-yoked VI had no lasting effect on the DRL response rates. The mean response rate for the first half of the session over the last four sessions of DRL 10-sec training (Condition 1) was 16.8 for Group 1 and 12.3 for Group 2. The mean response rate under the DRL component during the last four sessions under the mult DRL 10-sec yoked VI training (Condition 2) was 18.2 for Group 1 and 11.7 for Group 2. The elevated response rates for Group 1 were due to one pigeon, P4. The corresponding means for the other three pigeons were 13.6 and 13.3 responses/min. Thus the response rate of Group 1 was greater than the response rate of Group 2 by 4.5 responses/min under the first half of the DRL 10-sec schedule and by 6.5 responses/min during the DRL component of the mult schedule. Although these differences were the result of one bird, the data of Group 2 cannot be considered a direct extension of Group 1 (see Figure 2). However, as all compari-

sons were within-group comparisons, the validity of the conclusions was not affected.

Figure 1 presents the relative frequency distributions of IRTs for the first half of the DRL 10-sec schedule (Condition 1) and the DRL component of the mult DRL 10-sec VI schedule (Condition 2). The VI relative frequency distributions for Condition 2 are presented in Table 2. The DRL distributions were very similar within pigeons, with the exception of P4. The DRL distribution for the mult schedule for P4 was monotonically decreasing, more characteristic of a VI distribution or a DRL distribution with a 1 or 2 min DRL value (see Richardson & Loughhead, 1974b). If induction occurred from the VI schedule to the DRL schedule, it should cause an increase in relative frequency at the lower IRTs. Such an increase was seen in the data of P3 and P4; however, P1, P5, and P6 showed no effect, while P2, P7, and P8 showed a decrease in relative frequency in this region. Table 2 shows that when the VI component was in effect most IRTs were less than 2 sec.

The top panels of Figure 2 present the mean response rate data as a function of schedule value for both the DRL and VI schedules. Analyses of variance were performed on the data from the first exposure

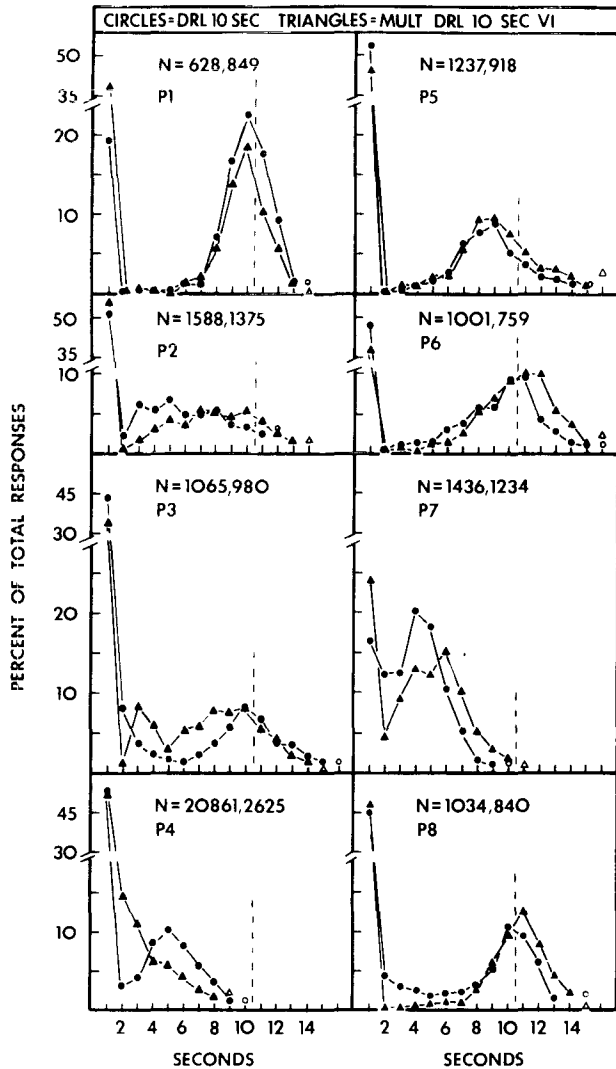


Figure 1. Relative frequency distributions for the first half of DRL 10 sec (Condition 1, circles) and the DRL 10-sec component of mult DRL 10-sec VI schedule (Condition 2, triangles). Each function is the mean over the last four sessions of a condition. The rightmost filled symbol is the 15-sec IRT or the largest IRT with 1% or more of the total responses. The open symbols represent the cumulative relative frequency for that and larger IRTs. N = total number of responses represented by the distribution for the DRL 10-sec schedule and the distribution for the DRL 10-sec component of the mult DRL 10-sec VI schedule. The numbers on the abscissa represent the nominal upper limit of the class interval, e.g., 5 contains all IRTs from 4.00 to 4.99 sec.

to each condition, i.e., the points connected by lines in the top panels of Figure 2. Each point is a group mean over the last four sessions of a condition. Separate analyses of variance showed that response rate decreased as schedule value increased for Group 1, $F(5,33) = 5.96, p < .001$, and Group 2, $F(7,45) = 2.48, p < .05$. The schedules differed in response rate, Group 1, $F(1,33) = 63.66, p < .01$; Group 2, $F(1,45) = 67.22, p < .001$. The schedules did not interact with schedule value for either Group 1,

$F(5,33) = 1.26$, or Group 2, $F(7,45) = 1.60$. The redetermined points showed a higher response rate during the DRL component for three out of four cases in Group 2 and were different from the original response rates for two out of five cases for Group 1. This metastability is common for the DRL schedule (Staddon, 1965; Zeiler, 1972). The reinforcement rates varied with schedule value and are presented in Table 1.

The ratio of number of responses emitted during the VI component to total number of responses emitted during both components (relative response rate) was computed for the last four sessions of each condition for each pigeon. The group means of relative response rate are presented as a function of schedule value in the bottom panels of Figure 2. The relative response rates for the first exposure to each schedule value (points connected by lines in Figure 2) were normalized by the arcsin transformation and tested for significance by analysis of variance. Group 2 showed no effect of schedule value on relative response rate, $F < 1.00$, while Group 1 showed an increase in relative response rate as the schedule value increased, $F(5,15) = 6.01, p < .01$. A comparison of the relative response rates for the .5- and 1-sec schedule value with the remaining schedule values of Group 1 was significant, $F(5,15) = 27.8, p < .01$, using the Scheffé Method.

The cumulative records for Group 1 showed that each pigeon responded at a higher rate during the VI component than during the DRL component under each condition. The response rate changed from a steady low rate to a steady high rate at approximately the time the stimulus signaled the change from DRL to VI. This abrupt change in rate was characteristic of all pigeons in Group 1, although, occasionally the rate change was not perfectly correlated with the stimulus change.

Table 2
Relative frequency of response for the VI Component of Condition 2 (DRL 10 VI)

Class Interval* (sec)	Pigeon							
	P1	P2	P3	P4	P5	P6	P7	P8
1	72	95	82	75	99	97	50	92
2	21	9	14	17			20	3
3	3	1		4			10	
4				2			7	
5				1			5	
6							3	
7							2	

*All percentages of 1 or larger are given. The data represent the means over the last four sessions.

†The class interval number is the nominal upper limit of a 1-sec width interval, e.g., the interval 5 includes all IRTs from 4.00 to 4.99 sec.

Cumulative records for pigeons in Group 2 showed that when the schedule value ranged between 10 and 45 sec in Conditions 2 through 6, the response rate was low during the DRL component and changed to a high rate when the stimulus signaled the VI component change. In Condition 7, the schedule value remained at 45 sec, as in Condition 6, while the stimulus lights were reversed. In this condition, only one pigeon (P8) recovered the response pattern observed under Conditions 2 through 6, i.e., a change from a low response rate to a high response rate when the stimulus changed. The other three pigeons began each session with a low response rate but abruptly changed to a high rate sometime during the DRL component. Figure 3 shows representative cumulative records for one of the pigeons in Group 2 during Conditions 3, 5, 6, and 7.

When the schedule value was 60 or 120 sec in Conditions 8 and 9, the response rate sometimes changed when the stimulus changed but the relation was not as strong as under the lower schedule values. Occasionally, the response pattern remained erratic through the session. Figure 4 shows cumulative records for one pigeon in Conditions 8 and 9. When the pigeons in Group 2 were retested under schedule values of 45, 20, and 10 sec, in Conditions 10, 11, and 12, cumulative records showed a low rate under the DRL component which changed to a high rate at the beginning of the VI component. The high rate was maintained throughout the VI component, as had been observed under the original exposures to these schedule values.

Under the 300-sec value of the multiple schedule in Condition 13, periods of high response rate were interspersed among periods of very low response rate. Usually, the rate changes occurred late in the VI component, not at the stimulus change. Other sessions would show no abrupt rate change.

Discussion

At all schedule values, response rates were higher in the yoked VI component than in the DRL component of the multiple schedule. Although this appears to indicate that the pigeons is sensitive to the differential consequences of IRTs over a range from .5 to 300 sec, certain considerations suggest that this conclusion must be qualified.

First, at the .5-sec schedule value, every response during the DRL component was reinforced for P3 and P4, and thus differential reinforcement of IRTs could not be responsible for the lower rate in the DRL components. This result is understandable from a consideration of the properties of the mult DRL yoked VI schedule when the schedule value is low. As the DRL value approaches zero, every keypeck during the DRL component will exceed the IRT

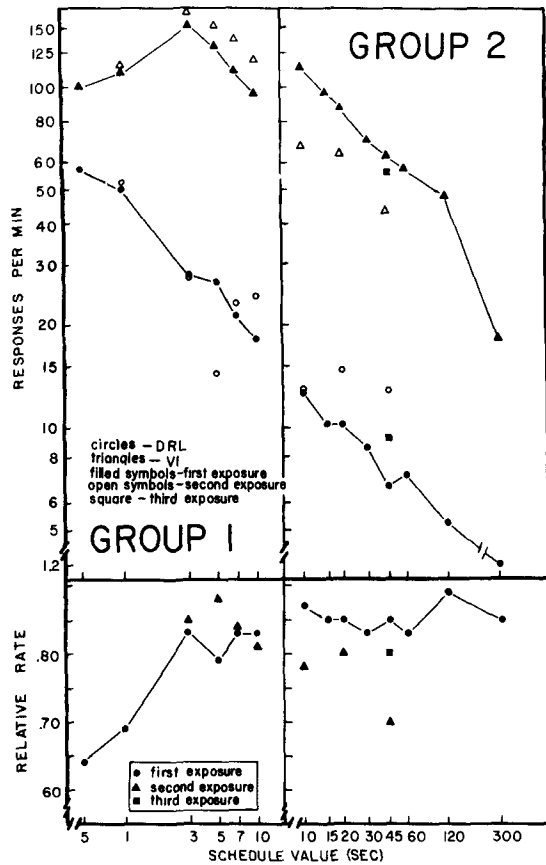


Figure 2. Responses per minute as a function of schedule value for Group 1 (top left panel) and Group 2 (top right panel) for the DRL and the VI components of the multiple schedule. Points connected by a line represent the first exposure to each schedule value. The bottom panels present the relative response rate statistic for the response rates presented in the top panels (VI responses per minute/total responses per minute). Note that the schedule value and response rate are plotted on logarithmic scales, while relative rate is plotted on a linear scale. Each point is the mean of the last 4 days of testing under a condition.

requirement and will be reinforced. However, every keypeck will not be reinforced on the yoked VI schedule, because of variability in behavior. Under the low-value DRL schedule, a pigeon will generate variable interreinforcement times and it is unlikely that the longer interresponse times during the VI component will exactly coincide with the longer interreinforcement intervals generated on the DRL component. Consequently, the pigeons are likely to emit a rapid sequence of unreinforced keypecks during the longer interreinforcement intervals on the VI component and thereby show higher response rates than on the DRL component. The higher rate of reinforcement in the DRL component than in the VI component under DRL values of 1 and .5 sec is understandable in terms of the above reasoning. There was little or no difference in the rates of rein-

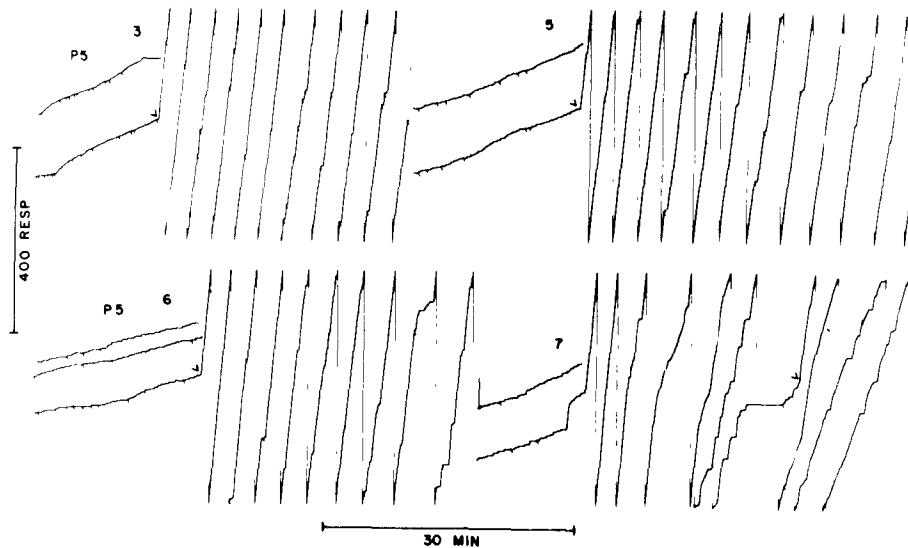


Figure 3. Cumulative records for P5 recorded during terminal sessions of the experimental conditions identified by numbers (see Table 1), 3 = 15 sec, 5 = 30 sec, 6 = 45 sec, 7 = 45 sec with cue light colors reversed. Reinforcer presentations are indicated by offsets of the response pen. The Vs show the point of schedule change. The initial parts of each record have been overlapped and the last part of the sessions have been deleted from some records.

forcement of the DRL and VI components at the other schedule values.

Second, as the schedule value was increased from 3 to 300 sec. both the response rate and the reinforcement rate decreased, yet the relative rate remained constant. That is, the number of responses emitted during the DRL component was a constant proportion of the total responses independent of schedule value. This finding indicates that, within the range studied, the relative effect on responding of requiring a minimal IRT for reinforcement does not depend on the size of that minimal IRT. Rather, the decrease in response rate that occurs when the schedule value is increased is due solely to the consequent decrease in reinforcement rate, which causes a decrease in response rate, which causes an increase in reinforce-

ment rate, etc., until an equilibrium point is reached where the reinforcement rate will support the response rate.

Third, certain procedural details may have contaminated the results obtained in this experiment. In particular, the pigeons had a long history of exposure to low schedule values prior to exposure to the large schedule values so that the high relative response rates under the large schedule values may have been a carry-over from earlier training. Also, the DRL component always preceded the VI component within a session so that any time-related effects such as "warm-up" causing a higher response rate toward the end of the session would affect the relative response-rate measure. Experiment II investigated both of these possibilities.

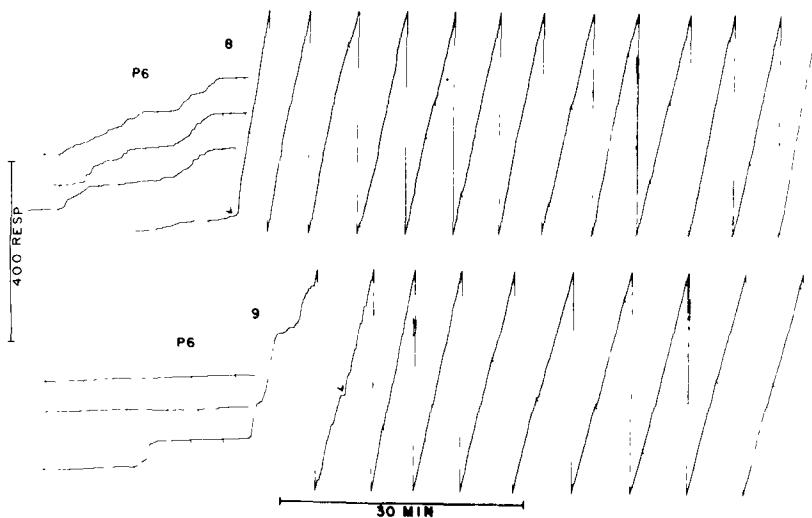


Figure 4. Cumulative records for P6, Conditions 8 (60 sec) and 9 (120 sec). Details are the same as for Figure 3.

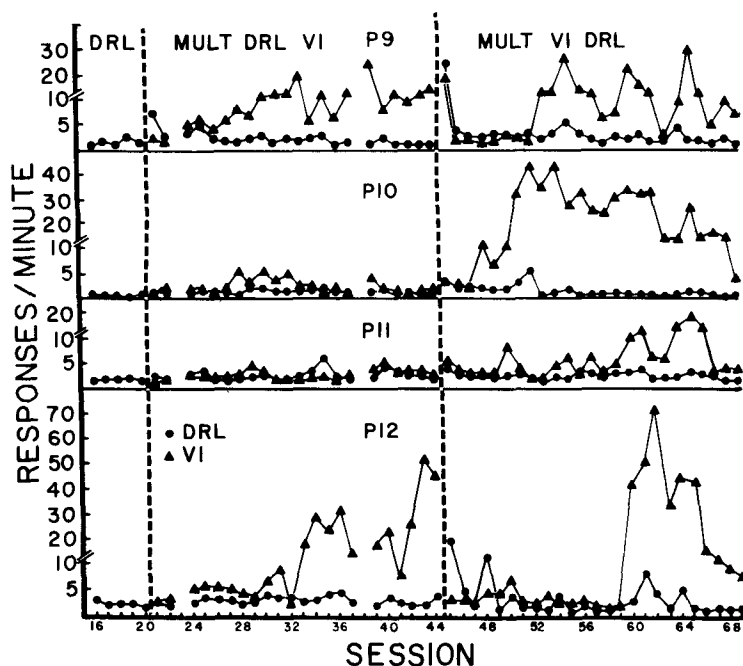


Figure 5. Response rates for the last five sessions of the DRL schedule and all sessions of the multiple schedule. The data for Sessions 23 and 38 were lost.

EXPERIMENT II

Experiment II employed experimentally naive pigeons to investigate the rate of keypecking in the two components of a mult DRL yoked VI schedule with a 180-sec schedule value. Initially, the multiple schedule was arranged with the DRL component occurring during the first half of the session, as in Experiment I. After responding stabilized, the order of the components was reversed so that the VI component occurred during the first half of the session.

Method

Subjects. Four naive, adult racing homing pigeons (P9, P10, P11, P12) were maintained at 70% of their free-feeding weights during preliminary training and at 75% of their free-feeding weights during the experiment proper.

Apparatus. The apparatus were the same as in Experiment I.

Procedure. Each pigeon was adapted to its test chamber, magazine trained, and pretrained for five sessions in which every response was reinforced. The pigeons were shaped by the method of successive approximations to peck the key during the first session of regular reinforcement. The key light was red during preliminary training. Next, the pigeons were trained under a DRL-180 sec schedule for 20 sessions with the key light alternating between red and green on a daily basis. The pigeons were then trained under the mult DRL 180-sec yoked VI schedule for 24 sessions. The key light was red during the DRL component and green during the VI component. Finally, the within-session order of the schedule components and key colors was reversed for 24 more sessions. The VI component and the green key light was present during the first half of the session; the DRL component and the red key light was present during the second half of the session. During this final phase, the programmed interreinforcement times of the VI component were composed of the interreinforcement times from the DRL component of the previous session. Conditions were changed when each pigeon had five successive sessions where the DRL response rate showed no sys-

tematic change. Session duration was 4 h throughout the experiment proper. The session duration was limited by the availability of the test facilities. All other details were the same as in Experiment I.

Results and Discussion

Figure 5 presents the response rates during the last five sessions of DRL 180-sec training and all sessions of the multiple schedules. During the mult DRL 180-sec yoked VI schedule, P9 and P12 developed a higher response rate under the VI component than under the DRL component. During the mult yoked VI DRL 180-sec schedule, all pigeons developed a higher response rate under the VI component than under the DRL component. Except for some short, transitory increases after changes in conditions, the DRL response rate generally remained low and stable throughout training. There was no sustained induction from the VI to the DRL component.

The pattern of responding for each of the three conditions is shown by cumulative records in Figure 6 for Pigeon P9. There was a low rate of responding under the DRL 180-sec schedule. Pigeons which had differential rates of responding under the multiple schedules responded at a low rate throughout most of the session. A period of high rate responding occurred during the VI component. When the VI component occurred during the last half of the session, the high rate responding abruptly started during the latter part of the VI component and continued until the end of the session. When the VI component occurred during the first half of the session, the birds started with a high response rate and abruptly changed to a low response rate before the

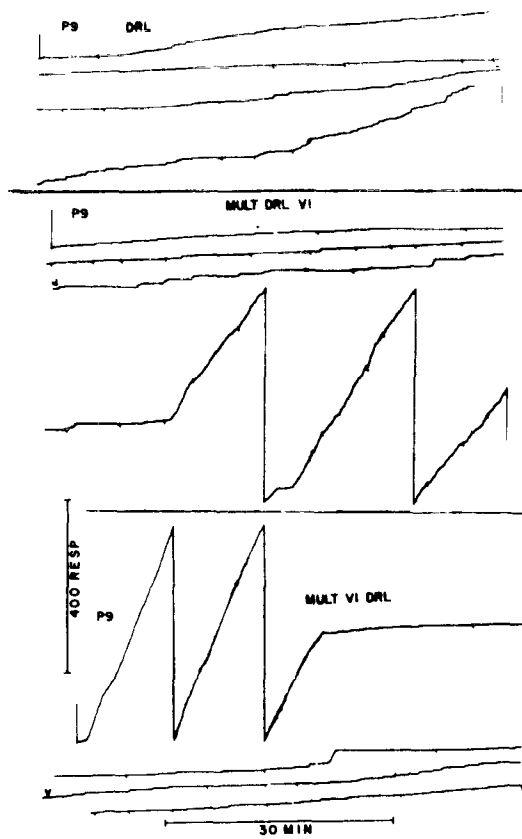


Figure 6. Cumulative records for P9. Details are the same as for Figure 3.

VI component terminated. This effect was striking and consistent for all pigeons in Experiment II. That is, the changes in rate were not correlated with changes in the key color and reinforcement schedule, although the high response rates were confined to the VI component.

The relative response rate was .56 for both P10 and P11 during the mult DRL VI condition where the differential response rate failed to develop. The relative response rates were .95 and .93 for P9 and P12, respectively, during the mult DRL VI condition. During the mult VI DRL condition, the group's mean relative response rate was .88, which is in the range of relative response rates seen in Experiment I. In all cases, the relative response rates are means over the last four sessions of a condition.

The results of Experiment II are consistent with those of Experiment I, showing that the results of Experiment I were not dependent upon a history of exposure to lower schedule values or to the within-session order of components.

GENERAL DISCUSSION

The most important finding of this study is that while pigeons are sensitive to the formal requirement

of a minimal IRT for reinforcement, this sensitivity is independent of the size of that requirement, at least over the range of 3 to 300 sec. In comparing response rates on DRL and VI schedules equated for reinforcement density and distribution, it is as though a constant in an equation relating response rate to reinforcement rate is set at different values for the two schedules. The effect of changes in DRL value on response rate seems to be completely accounted for by rate of reinforcement. This result seems at variance with theories of reinforcement schedules which stress IRT discrimination and differentiation (Anger, 1956; Morse, 1966; Shimp, 1973). This is not to say that pigeons cannot be sensitive to different minimal IRT requirements under other conditions, but this is not the case for the DRL schedule. Parametric manipulations of schedule value of the DRL schedule show the effect of varying rate of reinforcement for the dependent measure of response rate.

As this result might in some way be an artifact of the mult schedule, relative rates were computed from the data of Experiment II of Richardson (1973) where the DRL schedule and yoked VI schedule were administered successively; i.e., all DRL training was completed before the yoked VI training. For the three pigeons in that study under a 15-sec schedule value, the mean relative response rate was .85, approximately the same as found in the present study. The two rats in that study had a mean relative response rate of .88, a suggestive similarity.

The difference in response rates between the DRL and VI schedule can be explained by the concept of delay of reinforcement and the strengthening effects of the reinforcer on behaviors that precede the reinforced response (Catania, 1971). In the DRL schedule, the minimal IRT requirement of t sec insures that the peck response has not occurred for t sec prior to the reinforced peck. As behaviors other than pecking occur during this time, they are reinforced, with some delay, and may compete with pecking. The extensive literature on collateral behaviors under the DRL schedule is consistent with this view (Laties, Weiss, & Weiss, 1969; Richardson & Loughhead, 1974a). However, under the VI schedule, the peck response may occur during the t sec prior to the reinforced peck and the delayed reinforcement of these peck responses has a rate-enhancing effect on pecking, a source of strengthening of pecking which does not occur under the DRL schedule. A last note must be added to complete this analysis: not all other behaviors compete equally with pecking. For example, Richardson and Loughhead (1974a) found that DRL response rate greatly increased when the pigeons were prevented from making gross body movements, presumably because these behaviors were more successful competitors than the fine movements the birds could make when physically

restrained. Likewise, Laties et al. (1969) found that, in rats, the rate of reinforcement on a DRL schedule increased while the barpress rate decreased if the rats were allowed to gnaw on wooden blocks. When the wood was not present, other behaviors occurred prior to the reinforced response, but they did not compete with barpressing successfully as did gnawing. The manipulations which affect the occurrence of collateral behaviors are ones which vary the kinds of responses available to the subjects. Possibly, different kinds of responses are differentially sensitive to reinforcement, or the effect may be due to physical incompatibility and/or other factors which preclude the simultaneous occurrence of the collateral behavior and the required response. In summary, it is suggested that the requirement of a minimal IRT for reinforcement reduces response rate below that of a yoked VI schedule by determining which behaviors receive reinforcement at delays of t sec or less prior to the reinforcement-producing response.

In both experiments of the present study, no lasting effect on DRL response rate was observed when the schedule was changed from DRL to mult DRL VI. Other experiments have reported interactions between the components of a mult DRL VI schedule. Weisman (1969) tested pigeons on a mult VI 1-min DRL schedule where the DRL value was adjusted so that the rate, but not distribution, of reinforcement between the two schedules was approximately equal. The response rate during that VI component of the mult VI DRL schedule was greater than when a mult VI 1-min VI 1-min schedule was used (behavioral contrast). Bloomfield (1967) compared the response rate of pigeons under a mult DRL VI 1-min schedule with the response rate to the DRL schedule in isolation. At several values of the DRL schedule, the response rate for DRL was higher under the multiple schedule than when the DRL schedule was presented alone (induction). The present failure to find a sustained interaction between the components of the multiple schedule was probably due to the procedure of having one transition per session from DRL to VI. Both Weisman and Bloomfield had several transitions per session. However, the possibility exists that the lack of interaction was due to the equalization of both frequency and distribution of reinforcement in the two components by the yoked control procedure. The present study did not include a test for the effect of the DRL schedule on the VI response rate in the mult schedule.

The present data support the position of Reynolds and McLeod (1970), that performance on DRL schedules does not involve the differential reinforcement of interresponse times. Reynolds and McLeod (1970) cite one study (Reynolds, 1966) which may show that pigeons discriminate IRTs. In that study, pecks to a blue key were reinforced on a VI schedule

only if two pecks to a red key, which preceded the blue key, were separated by 18 sec or more. The results showed that the pigeons did not selectively emit long IRTs to the red key, but their rate of pecking on the blue key showed that they discriminated the previous IRT to the red key. This result is paradoxical only if one assumes that the pigeon can discriminate time since the last peck before emitting the peck establishing the IRT. An alternative view is that the pigeon cannot discriminate time since the last peck until it emits a peck. In this case, time since the last peck cannot be a controlling variable for the peck which establishes the IRT. A discrimination of IRT duration in this manner would account for responding under the special conditions where a prior IRT predicts present reinforcement conditions, such as Reynolds set up. It would also account for the lack of sensitivity of the pigeons' keypeck to differential reinforcement of long IRTs in conditions such as those investigated in this paper.

REFERENCES

- ANGER, D. The dependence of interresponse times upon the relative reinforcement of different interresponse times. *Journal of Experimental Psychology*, 1956, **52**, 145-161.
- BLOOMFIELD, T. M. Behavioral contrast and relative reinforcement frequency in two multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 151-158.
- CATANIA, A. C. Reinforcement schedules: The role of responses preceding the one that produces the reinforcer. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 271-287.
- FERSTER, C. B., & SKINNER, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- KRAMER, T. J., & RILLING, M. Differential reinforcement of low rates: A selective critique. *Psychological Bulletin*, 1970, **74**, 225-254.
- LATIES, V. G., WEISS, B., & WEISS, A. B. Further observations on overt "mediating" behavior and the discrimination of time. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 43-57.
- MORSE, W. H. Intermittent reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 52-108.
- REYNOLDS, G. S. Discrimination and emission of temporal intervals by pigeons. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 65-68.
- REYNOLDS, G. S., & MCLEOD, A. On the theory of interresponse-time reinforcement. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 4). New York: Academic Press, 1970.
- RICHARDSON, W. K. A test of the effectiveness of the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 385-391.
- RICHARDSON, W. K., & LOUGHEAD, T. E. The effect of physical restraint on behavior under the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 455-461. (a)
- RICHARDSON, W. K., & LOUGHEAD, T. E. Behavior under large values of the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 121-129. (b)
- SHIMP, C. D. Sequential dependencies in free-responding. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 491-497.

STADDON, J. E. R. Some properties of spaced responding in pigeons. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 19-27.

WEISMAN, R. G. Some determinants of inhibitory stimulus control. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 443-450.

ZEILER, M. D. Reinforcement of spaced responding in a simultaneous discrimination. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 443-451.

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